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Accessibility appraisal of integrated land-use/transport strategies: methodology and case study for the Netherlands Randstad area

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Abstract. Conventional approaches to measuring accessibility benefits are not capable of fully measuring the total accessibility benefits of integrated land-use/transport strategies, where both land-use and transport changes form part of the policy strategy. In this paper, a comprehensive methodology for analysing accessibility impacts and accessibility benefits, based on location-based and utility-based accessibility measures within an integrated land-use/transport interaction-modelling framework is described and applied in a case study. The case study examined the accessibility benefits and related user benefits of intensive and multiple land use strategies aimed at increasing the density and diversity of activities around railway stations for the Netherlands Randstad area for the 1996-2030 period. It is shown that heavy concentrations of activities near railway stations result in decreasing marginal returns for public transport users and disbenefits to car users.

1. Introduction

Accessibility, a concept used in a number of scientific fields such as transport planning, urban planning and geography, plays an important role in land-use and transport policy-making. However, finding an operational and theoretically sound concept of accessibility is quite difficult and complex, as seen in the review of Geurs and Van Wee (2004). Conventional approaches to accessibility measurement typically include congestion levels, travel times or costs as accessibility measures, describing the performance of the infrastructure network. These 'infrastructure-based' accessibility measures are often standard output of transport models and are easy to interpret for researchers and policy makers, and are also used as an input for economic appraisal (cost-benefit analysis), where access or travel costs are used as input for the well-known rule-of-half measure of consumer surplus. However, this conventional approach has important shortcomings for accessibility evaluation and economic appraisal of land-use, transport and integrated land-use/transport policy strategies, as the result of the exclusion of the land-use component of accessibility. Firstly, the impact of land-use changes arising from transport investments is ignored, for example, the impact of improved travelling speed on urban sprawl. Secondly, infrastructure-based accessibility measures do not correctly measure accessibility impacts of land-use strategies that affect the spatial distribution of activities. Although the indirect impact of land-use changes via speed on the road network (e.g. more congestion) may be included and expressed in these measures, generally speaking and far more important, the direct effect is not. Because of the strong interdependencies between the land-use and transport systems this may strongly affect the result of accessibility benefit estimations.

In this paper we aim to improve the current evaluation practice by presenting a more comprehensive appraisal framework to measure accessibility impacts and related user benefits of land-use and transport policy strategies within an integrated land-use/transport system. The appraisal framework is based on ‘location-based’ and ‘utility-based’ accessibility approaches that are theoretically more satisfying than ‘infrastructure-based’ approaches and still relatively easy to interpret for researchers and policy-makers. We focus our appraisal framework on the assessment of integrated land-use/transport planning strategies, in particular, intensive and multiple land-use planning strategies. Since the late 1990s, intensive and multiple land-use planning has received increasing attention among planners and policy-makers in the Netherlands and elsewhere. The aim was to promote efficient use of scarce land and a better quality of life in the cities, and to preserve natural environments (see, for example, www.multiplespaceuse.com for an overview of projects). Intensive and multiple land-use planning concentrates on intensification of activities (concentration of urban activities in high densities) and increasing the number and/or the dispersion of different land-use functions (e.g. better mixing of housing, business and retail functions). In urban areas, intensive and multiple land-use planning is often integrated with infrastructure planning. In the Netherlands, the construction of high-speed railway links connecting major cities to the European high-speed rail network has stimulated the Dutch government to launch railway station reconstruction and urban renewal projects. The high-speed railway station areas are to become locations with intensive use of urban space and a balanced mix of dwellings, businesses and urban facilities (VROM, 1998b).

Despite increasing attention, however, the benefits of intensive and multiple land-use (ILU) strategies are not well understood. Firstly, the definition of multiple land use is rather problematic and cannot be stretched too far, i.e. the larger the spatial scale and the further land-use functions are subdivided (home, work, retail etc.), the greater the number of land-use functions, and the more frequent an area can be characterised as multiple land use (Priemus et al., 2000). To overcome this problem, the geographical scope of intensive and multiple land-use areas in our case study is limited to railway stations and their surrounding area, and a limited number of functions at ILU locations (i.e. housing, commercial and non-commercial employment) are distinguished. Secondly, an appraisal framework for assessing the land-use, transport, accessibility and societal impacts of intensive and multiple land-use strategies is currently lacking. In this paper we focus on accessibility impacts and related economic benefits. The appraisal of integrated land-use/transport policies and, in particular, intensive multiple land-use planning, introduces a range of research challenges related to identification and measurement of accessibility and related user benefits within integrated land-use/transport systems. Here, we will, firstly, discuss these research issues and present an appraisal framework to address these (section 2). Secondly, the appraisal framework is applied in a case study for the Netherlands Randstad area for 1996-2030, using a high-resolution land-use/transport interaction model to simulate land use, transport and accessibility impacts at the local and regional level (section 3). Section 4 presents the conclusions, and section 5 sets out directions for further research.

2. Appraisal framework

2.1 Introduction

A thorough evaluation of the accessibility impacts and user benefits of land-use/transport investment strategies, and, in particular, intensive and multiple land-use strategies, raises several research challenges related to the identification and measurement of accessibility impacts and benefits that users of the land-use/transport system accrue from accessibility changes. In this paper, three research issues are addressed: (i) the inclusion of feedback mechanisms between land-use and transport system changes at appropriate spatial scales in accessibility measurement (Section 2.2.), (ii) the incorporation of spatial imbalances in the distribution of activities in accessibility measurement (Section 2.3), and (iii) the measurement of accessibility benefits accruing to transport users (Section 2.4).

2.2 Land-use and transport feedback mechanisms

The plausibility of an accessibility measure does not only depends on how it is operationalised and measured but also on the theoretical basis and practical limitations of the transport and land-use data and models used (Geurs and Van Wee, 2004). Ideally, all feedback mechanisms related to accessibility to the different components of accessibility need to be included. In other words, accessibility is a location factor for inhabitants and firms (relationship with land-use component), and influences travel demand (transport component), people's economic and social opportunities (individual component) and the time needed for activities (temporal component).

These interdependencies are particularly relevant when analysing integrated land-use/transport planning strategies, such as the intensive and multiple land-use planning around railway station areas in the Netherlands, aimed at both influencing location behaviour of population and firms (attracting new businesses) and travel behaviour patterns (increasing the demand for rail transport). The inclusion of feedback mechanisms between land use, travel demand and accessibility implies the use of land-use/transport-interaction models, which are typically capable of handling these impacts (see EPA, 2000; Miller et al., 1999; Wegener & Fürst, 1999 for extensive overviews). However, not many evaluation studies of the accessibility impacts of land-use and transport projects are based on such models, which is probably due to the complexity of the models. Furthermore, land-use/transport interaction models generally do not have a sufficient spatial resolution for evaluating land-use and transport impacts of land-use projects at the local level, and it is exactly the local level that is essential for the analysis of multiple land use. Thus, for a thorough evaluation of accessibility impacts, a high-resolution integrated land-use transport interaction framework is needed.

2.3 Accessibility measurement and spatial imbalances of activities

Land-use policies, in particular, intensive and multiple land-use planning, which involve a concentration of activities, may have positive and negative accessibility and economic benefits for commuters and visitors. There may be positive benefits due to a greater proximity of activities and markets (agglomeration benefits) within the same urban region but also negative impacts due to spatial imbalances in local labour markets. For example, concentrating firms in accessible central urban areas will improve job accessibility for workers. Clearly, if all firms were to relocate to central urban areas, the number of jobs would be much higher than the number of employees living within a reasonable travel time, and competition among firms for employees would sharply increase. Accessibility measures used should thus incorporate these job competition effects, which is not common practice. Here, we examine the inclusion of job competition effects in location-based and utility-based accessibility measures.

Location-based accessibility measures are a group of accessibility measures analysing accessibility at locations describing the level of accessibility to spatially distributed activities, for example, 'the number of jobs that can be accessed within 30 minutes travel time from housing locations'. Several types of location-based measures are used in land-use planning and, to a lesser extent, transportation studies (for an overview of references, see Geurs and Ritsema van Eck, 2001). The major advantage of location-based measures is that accessibility changes may be the result of transport changes, land-use changes or both. The measures are thus capable of evaluating integrated land-use/transport infrastructure planning strategies, in general, and multiple land-use strategies, in particular. Furthermore, they can generally be easily computed using existing land-use and transport data, and/or models, traditionally employed as input for estimating infrastructure-based measures.

The potential accessibility measure is the most popular location-based measure, and has been widely used in urban and geographical studies ever since the late 1940s. Potential measures estimate the accessibility of opportunities in zone *i* to all other zones in such a way that the more distant the opportunity, the more diminished the influence. The measure has the following form, assuming a negative exponential cost function:

$$A_i = \sum_{j=1}^{n} D_j e^{-\beta c_{ij}} \qquad (1)$$

where A_i is a measure of accessibility in zone *i* to opportunities D in all zones *j*, c_{ij} , the (generalised) costs of travel (e.g. time, trip costs, etc.) between *i* and *j* and β a cost sensitivity parameter. For the purpose of evaluating multiple land-use strategies, standard potential accessibility measures have the disadvantage of not being accountable for the spatial distribution of the demand for opportunities and capacity limitations of available opportunities. When, for example, job accessibility is studied, the exclusion of spatial imbalances in labour markets may result in inaccurate or even misleading results (Shen, 1998). Several authors have developed alternative accessibility measures to account for imbalances in the spatial distribution of activities and resulting competition effects (see Geurs and Ritsema van Eck, 2003, for a review). The balancing factors of the double constrained entropy model, originating from Wilson (1971), form a methodologically sound accessibility measure when both the spatial distribution of supplied opportunities (at destination locations) and the distribution of the demand for those opportunities (at origin locations) are relevant. This is the case for labour markets examined here, where workers compete with each other for jobs and employers compete with each other for employees. The balancing factors of the double constrained model serve to ensure that the magnitude of flow (e.g. trips) originating from and destined for each zone equals the correct number for that zone (e.g. inhabitants or jobs). The balancing factors a_i and b_j are represented in the following equations:

$$a_i = \sum_{j=1}^{n} \frac{1}{b_j} D_j e^{-\beta c_{ij}} \quad \text{and} \quad b_j = \sum_{i=1}^{m} \frac{1}{a_i} O_i e^{-\beta c_{ij}} \qquad (2,3)$$

where O_i and D_j are the number of opportunities at origin zone *i* and destination zone *j*, c_{ij} the (generalised) costs of travel and β a cost sensitivity parameter. Locations which are well-accessible have a balancing factor, a_i, smaller than 1, because the number of trips attracted should be reduced to equal the number of opportunities. As an accessibility measure, the inverse of a_i is thus more appropriate. The balancing factors are mutually dependent and have to be estimated in an iterative procedure. This reflects the interdependent relationship between the spatial distribution of supplied opportunities and the demand for those opportunities. The balancing factors are less easy to interpret than, for example, the potential accessibility measure, as they can be identified only to an unknown multiplicative constant. Hence an appropriate way to deal with them is to interpret them as indices so that relative changes in accessibility can be computed when transport costs or masses in zones change.

Utility-based accessibility measures are based on a random utility maximisation theory. The utility theory addresses the decision to purchase one discrete item from a set of potential choices, all of which satisfy essentially the same need. Two types of utility-based accessibility measures are proposed in the literature which are based on the multinomial logit model or the double constrained entropy model. The first approach interprets the denominator of the multinomial logit model, also known as the logsum, as an accessibility measure. Ben-Akiva and Lerman (1985) noted that a major difficulty with the logsum as accessibility measure is that different specifications of the multinomial logit model result in accessibility values that are expressed in different units and cannot be compared.

This can be overcome by converting it to monetary, and thus comparable, units by dividing the logsum by the travel-cost coefficient (Equation 4) (Ben-Akiva & Lerman, 1985):

$$A_i = \frac{-1}{\beta}\ln(\sum_{k=1}^{m} e^{V_k}) \tag{4}$$

where A_i denotes the accessibility benefit (in monetary value), and v_{ij} the indirect, or observed transportation, temporal and spatial components of utility, while β is the cost coefficient. Note that the cost coefficient in Equation 4 is negative, reflecting that higher costs result in lower utilities. To change this to marginal utility rather than marginal disutility of travel costs, the cost coefficient is simply multiplied by -1. If v_j is taken as the potential number of activities (jobs, population) within reach, the measure is essentially a monotone increasing function of the potential accessibility measure as defined in (1). The logsum benefit measure has the advantage that it can be linked to microeconomic theory, allowing for calculations of consumer surplus or, alternatively, compensating variation. Small and Rosen (1981) showed that, in the absence of income effects, compensating variation can be derived by dividing the logsum by the marginal utility of income, i.e. $\partial v_{ij}/\partial y_i$ where y_i is the individual's income. The logsum measure, however, is not often used in practical applications. Examples are found in Niemeier (1997), who analysed mode-destination accessibility for home-to-work trips in Washington State and Levine (1998), who analysed the influence of job accessibility on residential housing locations.

A second approach to measuring utility-based accessibility is based on the doubly constrained entropy model, which is followed in the rest of this paper. Martínez (1995) obtained the following accessibility measures:

$$A_i = \frac{-1}{\beta}\ln(a_i) \quad \text{and} \quad B_j = \frac{-1}{\beta}\ln(b_j) \tag{5,6}$$

where A_i represents the relative accessibility benefit travellers derive at each origin zone i (or the expected benefits per trip generated), and A_j, the relative attractiveness of destination zone j (or the expected benefit per trip attracted) for a given transport situation and subject to trips complying with total trip origins and destinations from the entropy model. The terms a_i and b_j have already been defined in Equation 3. Note that the entropy model and the multinomial logit model are equivalent formally at the same level of aggregation (Anas, 1983), which provides theoretical economic interpretation of the parameters of the entropy and logit models as external or market constraints reflecting competition effects. However, despite its theoretical merits, utility-based accessibility measures are seldom applied in land-use or transport policy appraisal. In the next section, we demonstrate how the utility-based approach to measuring accessibility can be used as input for economic appraisal of land-use and/or transport strategies.

2.4 Accessibility and user benefit measurement

Land-use and transport planning strategies, and particularly multiple land-use strategies, may have a range of economic impacts (see Nijkamp et al., 2003, for a discussion). These benefits are often grouped to direct and indirect economic benefits (e.g., Eijgenraam et al., 2000). Direct benefits are the benefits consumers derive from the proximity to various types of services and activities, reducing travel time and costs carried out a given individual or household activity programme, or increasing the number of activities in which one participates with the same travel time. A clear example is provided by multi-purpose trips to shopping centres. Indirect economic benefits may involve agglomeration benefits (higher productivity due to closer proximity and lower travel costs to markets for various inputs and outputs within the same region), output diversity (the supply of a variety of goods and services at a location may attract more consumers) and economics of density (large use of given equipment or infrastructure, leading to lower cost per unit). Here, we focus on the direct economic impacts (user benefits) of accessibility changes.

As already noted in the introduction section, multiple land use is interpreted here as an integrated land-use/transport infrastructure planning concept. Within a land-use/transport interaction framework, where all land uses are affected by transport or accessibility changes, and all travel is affected by land-use changes, it might be possible to identify and measure the total accessibility benefits of integrated land-use/transport strategies, either in the land-use or the transport system (see also Martínez & Araya, 2000a; Simmonds, in press). Here, we will examine both approaches briefly.

In urban economics, measurement of land-use benefits focuses on the functioning of housing, real estate and land markets, taking Alonso's (1964) bid-rent framework as the starting point. Bid-rent theory assumes that consumers and firms compete for land, and under the assumption of perfect competition in economic markets, land lots are sold to the highest bidder (bid). The theory describes the prices (rent) which a household or firm is willing to pay at different locations (e.g. distances from the city centre) in order to achieve a certain level of satisfaction or profit (see McCann, 2001, for an elaborate description). The bid-rent framework also serves as the central theory in several land-use and land-use/transport interaction models. For example, URBANSIM (Waddell, 2001) and MUSSA (Martínez, 1996) are based on a bid-choice theory, which combines bid-rent theory with utility-maximisation theory; households and firms are allocated to locations where consumer surplus is maximised, using willingness-to-pay functions representing individual, location (e.g. housing quality, rent) and accessibility characteristics. Marshallian consumer surplus measures may then be derived as land-use benefit measures, defined as the difference between the willingness to pay (or real location value) and what the consumer actually pays for that location before and after a policy change. The Hicksian compensating variation measure may also be used. It would thus seem possible to measure the benefits of land-use/transport strategies within the land-use system using an appropriate (bid-choice) location model.

However, Martínez and Araya (2000a) demonstrate that benefits associated with a land-use project can be fully measured with bid-choice models, but benefits generated by a transport project cannot be fully measured. In the case of a land-use project (e.g. development of dwellings, offices and retail facilities near a residential area), the project will result in a change in the set of location attributes and thus location attractiveness. The benefits accruing to residents will be fully captured by the variation in the willingness-to-pay for that location, and benefits for residents who decide to relocate, can be measured by measuring the variation in willingness-to-pay for the location before and after the project. A transport project (e.g. a rail service improvement) would in the bid-choice model (when accessibility attributes are included in the willingness-to-pay for location function) also affect location attributes and willingness-to-pay.

In reality, however, it is difficult to identify and measure accessibility benefits in the land-use system. Firstly, Martínez and Araya (2000a) show - both in theory and in an empirical case study for the city of Santiago in Chile – that the benefits measured by a bid-choice model would normally underestimate total accessibility benefits because benefits retained by transport users are ignored. Only a fraction of accessibility benefits are transferred into the use system and percolate down into land rents. The less sensitive a population is to accessibility changes (i.e. the degree to which households and firms relocate to minimise transport costs), the larger the bias. Secondly, bid-rent theory assumes perfectly competitive economic markets, but this assumption is typically violated in land markets due to market imperfections and heavy market interventions, especially in the Netherlands. As already noted, Martínez and Araya (2000a) found empirical evidence that only a fraction of transport benefits are transferred into the land-use system and percolate down into land rents. SACTRA (1999) also stated that when the perfect competition assumption is dropped, equivalence between transport benefits and total economic benefits can no longer be assumed. Secondly, a change in location value is likely to be an amalgam of land-use and transport benefits, which, in practice cannot be easily separated. For example, the location value change used in the cost-benefit analysis of the Amsterdam South-Axis project (CPB, 2003) is based on expert judgement of real estate agents, and reflects ex ante expectations of the improvement in 'spatial quality'. This is a mixture of benefits derived from the concentration of economic activities, proximity to road and rail infrastructure, and to the Amsterdam Schiphol Airport. The obvious conclusion is that total accessibility benefits that users derive from an integrated land-use/transport project might be more easily examined in the transport system.

The conventional approach to measure accessibility benefits of transport strategies is to use the rule-of-half measure, originating from Tressider et al. (1968), as an approximation of Marshallian consumer surplus. The rule-of-half formula computes the total change in user benefits as the sum of the full benefit obtained by original travellers and half that benefit obtained by new travellers or generated traffic. This can be calculated by multiplying the average number of trips T_{ij} between a base scenario (0) and a scenario with a project (1) by the difference in travel costs (c_{ij}):

$$\Delta CS_{roh} = \frac{1}{2}\sum_{i}\sum_{j}\left(T_{ij}^{0}+T_{ij}^{1}\right)\left(c_{ij}^{0}-c_{ij}^{1}\right) \qquad (7)$$

To use the rule-of-half measure as a practical approximation of consumer surplus, a number of assumptions are made which generally do not hold but are accepted in transport policy appraisal. Firstly, the rule-of-half assumes that the demand curve is linear over the section being used to estimate changes in demand and cost. This is generally satisfactory for the levels of change normally brought about by new infrastructure projects. However, for measures which can result in large changes in demand, such as some traffic reduction measures, the rule-of-half can lead to significant errors (SACTRA, 1999). Secondly, and more important, the rule-of-half assumes that all accessibility benefits accruing to economic agents are attributable to generalised cost changes within the transport system. This is a convenient argument which has a practical outcome, because it is easier to identify and estimate the benefits/disbenefits accruing directly to travellers rather search for their more elusive manifestations further along the chains of reaction in other markets (SACTRA, 1999). Under the assumption of perfect competition in all (transport-using) sectors of the economy, the transportation consumers' surplus is shown to summarise the welfare effects of transport changes for consumers and producers of both markets (see Jara-Diaz, 1986, for example). However, some authors pointed out that the rule-of-half gives incorrectly measured welfare effects of land-use policy plans (e.g., Neuburger, 1971) and transport strategies where land uses are forecasted to change as a result of the strategy (e.g., Simmonds, in press). The problem is that the rule-of-half measure does not correctly measure total accessibility benefits (and thus welfare changes) when changes are introduced that are not attributable to generalised cost changes. In general, accessibility may change as a result of either a transport (generalised cost) change or a land-use change, but the rule-of-half measure only estimates benefits for the origin-destination combinations where (generalised) costs change. Hence, the measure does not account for changes in the relative attractiveness of locations due to land-use changes and related changes in trip distribution taking place for reasons other than transport cost changes. As a result, no differences in accessibility benefits are, for example, estimated between project alternatives in the cost-benefit analysis of the Amsterdam South-Axis project, even though the number of activities located around the railway station highly differ (e.g. employment levels envisioned vary from 10,000 to 32,500 jobs) (CPB, 2003). This clearly signifies an unsatisfactory result, since the number of people with good access to public transport facilities would increase. Under the assumption of perfect competition in all sectors of the economy where transport is used, the location benefits might be identified and measured within the land-use system, also being added to the benefits measured by the rule-of-half.

Thus, the total accessibility benefits of a transport project could be estimated by computing the accessibility benefits associated with changes in generalised transport costs in the transport system by the conventional rule-of-half measure. To this, could be added the accessibility benefits associated with changes in the attractiveness of locations (and not attributable to generalised cost changes) in the land-use system based on the willingness-to-pay functions of appropriate location models. However, as noted earlier, it is difficult to identify and measure the additional location benefits in the land-use system. An alternative approach to identifying and measuring the total accessibility benefits within the transport system is proposed in the literature based on utility-based accessibility measures. Utility-based measures can be directly linked to traditional micro-economic welfare theory (e.g., Cochrane, 1975; Leonardi, 1978; Neuburger, 1971; Williams & Senior, 1978). Therefore, these measures can be used to compute Marshallian consumer surplus in economic (cost-benefit) analysis of both land use and infrastructure policy lands. Using Martínez and Araya’s framework (2000b), an elemental trip-user benefit *Tub* for mode *m* is defined as:

$$Tub_{ijm} = \frac{-1}{\beta}\ln(a_{im}b_{jm}) \tag{8}$$

representing a unit of absolute benefit, perceived by a user travelling between zones , and j for a given transport situation. This will also be subject to trips complying with total trip origins and destinations from the entropy model. Martínez and Araya (2000b) derived Marshallian consumer surplus by using

ΔTub_{ijm} as the difference in user benefits between a situation without (tub_{ijm}^0) and with a project (tub_{ijm}^1):

$$\Delta CS_{ab} = \sum_i \sum_j \sum_m \left(T^*_{ijm} \Delta Tub_{ijm} - \frac{1}{\beta} \Delta T_{ijm} \right) \tag{9}$$

where T^*_{ij} denotes the average number of trips between situations 0 and 1. The user benefits in Equation 9 are composed of the benefits of trip distribution, measured by a pseudo-rule-of-half, and a macro-level correction to account for the benefits of an aggregated trip generation effect. The latter relaxes the overall constraint in the entropy framework, where total trips, trip origin and destinations are exogenously defined in each situation, and where these are relevant in the long term, when the total number of activities (O_i or D_j) changes in a study area as the result of a project. Furthermore, by using ΔTub_{ij} instead of the difference in generalised costs, CS_{ab} avoids the linear approximation of benefits embedded in the standard rule-of-half measure (Martínez and Araya, 2000b). Martínez and Araya (2000a) show that CS_{ab} correctly measures total user benefits accruing from accessibility changes when used within a land-use/transport interaction framework. The authors state that the use of an integrated land-use/transport interaction model that properly forecasts land-use-transport feedback mechanisms is an important condition. If the accessibility benefits are obtained from a partial transport equilibrium model, the results may be biased. The more sensitive the location behaviour of population and firms is to accessibility changes, the larger the bias.

In conclusion, utility-based accessibility benefit measures can be used to estimate the total accessibility benefits of integrated land-use/transport strategies from the transport model within an integrated land-use/transport interaction-modelling framework. To date, however, this approach has– to the authors' knowledge– not yet been applied in land-use and/or transport project appraisal. In the next section, we demonstrate this comprehensive framework in a case study for the Netherlands Randstad area.

3. Case study for the Netherlands' Randstad area

3.1 Introduction

To evaluate the accessibility benefits of intensive and multiple land-use strategies using the appraisal framework described in the previous section, we conducted a case study for the Netherlands Randstad area. The Randstad area is the most densely populated area in the western part of the country, comprising about 40% of the population and jobs located on 20% of the Dutch territory. Three scenarios were constructed for the Randstad for the 1996 −2030 period; a reference scenario describing a continuation of current land-use and transport trends and two quite extreme intensive and multiple land-use scenarios. Section 3.2 describes the scenarios. These have been purpose-built for this study and are not directly linked to existing land-use planning policies or policies currently under discussion. The scenarios constructed are characterised as 'what-if' scenarios, i.e. we assume the realisation of multiple-intensive land use at certain locations at a certain point in time, and are not concerned with the feasibility or acceptability of the assumed changes. The land-use, transport and accessibility impacts of the scenarios are simulated with a high-resolution land-use/transport interaction model, the Environment Explorer. Section 3.3 describes the model and section 3.4 the results of the case study.

3.2 Scenario construction in 1996-2030

The *reference scenario* shows a continuation of current land-use and transport trends in the Netherlands, incorporating current national land-use and infrastructure policies[1]. Here, we shortly describe the assumptions regarding socio-economic developments, land-use and transport infrastructure policies. National and regional socio-economic developments are taken from trend scenarios developed for the Fifth National Policy Document on Spatial Planning (Brouwer et al., 2002). In this scenario, national housing demand increases by 22% (1.4 million dwellings) between 1998 and 2030, and the number of jobs by 34% (2.1 million). Land-use pressure is especially high in the Randstad area; more than half of the absolute growth in national housing demand and employment can be allocated to the Randstad area. National land-use policies, as formulated in the Fourth National Policy Document on Spatial Planning (VROM, 1997) are also realised. This includes the realisation of planned new housing and employment locations up to 2015 which are to be concentrated in or near the existing urban areas. Transport infrastructure investments include planned road and rail investments for the period up to 2010. Public transport improvements include rail infrastructure capacity expansions and the introduction of a southbound high-speed rail link between the Amsterdam South-Axis, Schiphol Airport and Rotterdam, going on to Brussels and Paris (HST South), and an eastbound high-speed rail link between Amsterdam and Utrecht, going on to Arnhem, Düsseldorf and Frankfurt (HST East). See AVV, 2000, for a more detailed description).

Both currently and in the reference scenario, population and employment in the Netherlands are relatively well-mixed with relatively low densities, e.g. about 4% of employment in the Randstad area is located in central urban areas with average job densities of about 210 jobs per hectare (ABF, 1999). Two Intensive and multiple Land-Use (ILU) scenarios were constructed with quite an extreme concentration of employment and socio-cultural activities around railway stations, but differing in their degree of concentration. The *Intensive and multiple Land-Use Scenario 1* (ILUS-1) assumes a quadrupling of the average density of commercial and non-commercial services (relative to the reference scenario level) densities around the four future high-speed railway stations in the Randstad area (i.e.

Amsterdam World Trade Centre, Rotterdam CS, The Hague CS and Utrecht CS). Figure 1 shows the different locations within the Randstad area, which are assumed to have been realised between 2010 and 2030. About 480,000 jobs are redistributed in the direction of these locations; this comprises about one-third of the forecasted job growth for the Randstad area for 1998-2030. This represents, in turn, about 7% of the total jobs located in the Randstad in the reference scenario in 2030. The job densities assumed in ILUS-1 are comparable to several metropolitan areas elsewhere in Europe (e.g. the City of London currently has a job density of about 900 jobs per hectare, see www.statistics.gov.uk), but are very extreme compared to the level actually planned for the (four) HST railway station reconstruction and urban renewal projects. These involve about a total of 70,000 to 100,000 jobs (offices, retail and other) (VROM, 1998a). The *Intensive and multiple Land-Use Scenario 2* (ILUS-2) redistributes the same number of jobs as ILUS-1 but around 12 railway stations (see Figure 1). This implies, on average, a doubling of commercial and non-commercial densities at these locations. This scenario is still quite extreme in the Dutch context, e.g. the employment increase assumed at each of these locations is in the range of the most ambitious project alternative of the Amsterdam South-Axis project (between 32,000 and 53,000 – CPB, 2003). In both scenarios relatively low housing densities are assumed at ILU locations (about 15 dwellings per hectare) to derive population levels comparable to those planned at the four HST stations, which are in the range of 5,000 to 10,000 dwellings (VROM, 1998a).

3.3 The Environment Explorer

Land-use/transport interaction models are typically developed to simulate and evaluate land-use and transport-system changes and their interactions, incorporating the different rates of change. A great deal has already been written about underlying theories and modelling techniques of operational land-use/transport models (e.g. EPA, 2000; Miller et al., 1999; Wegener & Fürst, 1999). Land-use/transport interaction models need to meet a number of modelling requirements for land-use and transport policy appraisal. DSC/ME&P (1999) describe three broad requirements. Firstly, the land-use model’s estimates of the spatial location of activities should be based on a behavioural representation of the different spatial processes and actors involved, which, among other factors, implies a level of segmentation sufficient to assign the major observed differences to groups of homogeneous actors. It should be based on the strength of behavioural responses to be calibrated to match the real world's patterns. Secondly, the transport model’s estimates of travel demand patterns should reflect a consistent outcome of the interplay between all the major behavioural responses to changes in costs and characteristics of transport supply. Thirdly, the model should consistently link the full set of (long-term) land-use and (short-term) travel behavioural responses. For the evaluation of intensive and multiple land-use strategies, a fourth requirement also should be met. In other words, the model should have a sufficiently high resolution and link spatial processes at the local (project) level with processes at higher spatial levels, e.g. activities generated at the local level typically involve a redistribution of activities at the regional level.

However, applying these criteria would imply a level of complexity and detail that can probably never be achieved in practice. DSC/M&P (1999) conclude that none of the operational land-use/transport interaction models was, at the time of their review, able to meet the full set of criteria for a complete set of behavioural responses, even with the existing state-of-the-art modelling.

In this case study, the Dutch Environment Explorer (Engelen et al., 2003) was used to simulate the land-use, transport and accessibility impacts of the reference and ILU scenarios. For the purpose of this study, the Environment Explorer was sufficient in meeting the broad modelling requirements as presented above. The model simulates land uses, land cover and activities at a high resolution

(500 by 500-metre grid cells) for the entire territory of the Netherlands, links spatial processes at the local, regional and national levels, and models interactions between land use and transport in a bi-directional manner. At the national level, growth figures for population and activity per economic sector are fixed and derived from exogenous economic and demographic scenarios. At the regional level (consisting of 40 large administrative regions), the dynamic spatial interaction-based model simulates regional growth and inter-regional migration of activities and residents on the basis of the relative attractiveness of the regions. At the local level, this model uses the method of Cellular Automata to simulate spatial processes for 17 land-use categories (urban and non-urban) at a relatively high spatial resolution (25 ha cells) on a yearly basis for the period of 1996 to 2030. An important characteristic of Cellular Automata models is their dynamic behaviour. For each surface-area unit (or cell) and time period, the Cellular Automata model assesses the quality of its neighbourhood (a circular area with a radius of 4 km). For each land-use function, a set of rules determines the degree to which it is attracted to, or repelled by, the other functions present in the neighbourhood. If the attractiveness is great enough, the function will try to 'occupy' the location; if not, it will look for more attractive places. New activities and land uses invading a neighbourhood over time will thus change the function's attractiveness for activities already present and others searching for space. A conventional double constrained transport model estimates car and public transport travel for an average working day (24-hour period), incorporating road congestion effects at the spatial level of 345 transport analysis zones.

The transport model provides potential accessibility measures for different activities (workplaces, natural environments, recreational facilities, population) at the zone and grid-cell level as input for the regional and local land-use models for the subsequent time period (year). In this study, the transport model is run every five years to simulate time lags in the interaction between transport and land use;

accessibility levels are input to the regional and local land-use models every year but are recalculated every five-year period. Although the Environment Explorer has a relatively high spatial resolution, it models land-use and travel behaviour at an aggregate level, i.e. the model does not include a population segmentation, and observed differences in behavioural responses into groups of socio-economic population groups can thus not be accounted for. Hence, the land-use and transport forecasts must be interpreted as rough estimates of potential behavioural responses.

To evaluate multiple land-use strategies, a new version of the Environment Explorer was developed to enable the user to specify and allocate intensive and multiple land-use (ILU) functions. In the scenario study, ILU-grid cells with a user-defined number of inhabitants, commercial and non-commercial jobs per 500-metre grid cell are exogenously allocated near railway stations (replacing existing land-use functions), which endogenously influences the spatial behaviour of other land-use functions in their environment. All other (existing or new) housing and economic activities are allocated by the model, and may, as a result of the allocation of ILU-cells, be repelled or attracted, depending on the local attractiveness of the area (accessibility level), their demand for space and the availability of land at the regional level. Furthermore, the Environment Explorer was elaborated to estimate (location-based and utility-based) accessibility measures and (the rule-of-half and utility-based) consumer surplus measures as output indicators. For this, data and model parameters were used from the land-use modules (population and job distribution) and transport model (e.g., balancing factors per trip purpose, generalised transport costs, cost sensitivity parameters, trips).

3.4 Results

The concentration of commercial and non-commercial employment at the ILU locations resulted in a regional redistribution of employment within the Randstad area (total employment levels constant at Randstad level). Figures 2 and 3 show a job shift from suburban and peripheral regions in the Randstad area to the zones where ILU locations are allocated and heavy job density increases are assumed. The job increases at ILU locations are less extreme in ILUS-2, but result in more dispersed distribution of jobs among regions because economic activities at more locations are affected. To a much lesser extent, the ILU scenarios also affect the spatial distribution of the population (not shown), as population levels increase at ILU locations by about 4,000-6,000 inhabitants compared to the reference case for 2030) at the cost of suburban and/or peripheral regions. The simulations from the Environment Explorer show that for both scenarios, the heavy concentration of firms at ILU locations significantly influences the location behaviour of existing firms in the neighbourhood of ILU locations. Existing firms are attracted or repelled, depending on the attractiveness of the area and the regional demand for new activities. At the level of transport analysis zones, ILUS-1 shows a job growth (compared to the reference scenario in 2030) of about 70,000 for the Rotterdam Central Station (CS) zone, 80,000 for The Hague CS, 95,000 for Utrecht CS and 140,000 for the Amsterdam South-Axis. However, the number of jobs (120,000) at the ILU locations within these zones was (exogenously) allocated. Additional firms are attracted to the Amsterdam South-Axis due to the relatively high demand for commercial and non-commercial activities in the Amsterdam region and the high accessibility level, whereas firms are repelled at Rotterdam CS and to a lesser extent at The Hague CS and Utrecht CS, where the regional demand is much lower. Similar neighbourhood effects are exhibited in ILUS-2. The strongest neighbourhood effects are found at ILU locations located in close proximity to each other (in Amsterdam, The Hague and Rotterdam – see Figure 1). For example, at the local level about 40,000 jobs are exogenously allocated at ILU locations around The Hague CS, The Hague Hollands Spoor (HS) and Delft, but at the zone level a job growth of about 15,000, 60,000, and 5,000, respectively, was found.

Although the ILU scenarios constructed here are very extreme, they do illustrate that the level of concentration of economic activities actually planned at ILU locations must be carefully examined, taking into account the relative attractiveness of locations, the regional demand for economic activities and possible market responses. The redistribution of employment affects the results of the different accessibility measures at the local level but also at the level of the entire Randstad area. Table 1 presents the results for the Randstad area of the standard potential accessibility measure (Equation 1) and the utility-based balancing factor a_i (Equation 5).

The *potential accessibility measure* (based on Equation 1), which does not incorporate competition effects, shows that job accessibility increases when jobs are more concentrated on locations well-accessible by public transport. Furthermore, the number of jobs within reach by public transport increases on average for the Randstad area by about 5% in ILUS-1, and 3% for the less extreme ILUS-2. Figure 4 shows the regional differentiation of the potential job accessibility by public transport in ILUS-2. The highest accessibility levels are found in the central urban areas well-served by public transport. Locations where job densities have not increased, e.g. suburban areas, profit from the concentration of activities at railway stations in nearby towns. Furthermore, the potential accessibility measure shows that job accessibility by car is slightly reduced, which is the result of increased travel times due to congestion and the redistribution of jobs that in the reference scenario are located at places more accessible by car (suburban and peripheral regions). Note that the congestion effects are underestimated here, because the transport model used does not include a full local road infrastructure network and traffic within transport zones is not assigned to the network. In reality, the quite extreme concentration of activities, as envisioned in the ILU scenarios, will result in higher congestion levels on the local road network. The potential measure also illustrates that job accessibility by car is much greater than by public transport (an average of about a factor of 10 for the Randstad area). This is the result of higher average door-to-door travel times (including access and egress time) and the unfavourable locations of jobs with respect to public transport in general.

The results of the *utility-based balancing factor* a_i, based on equation 5, which represents the moneymetric benefits of job accessibility derived by travellers (for an average working day) at each origin zone, strongly differ from the potential measure. Firstly, the measure shows, in agreement with a priori expectations, public transport accessibility benefits to be higher in ILUS-2 than ILUS-1. This shows that if competition effects on the labour market are accounted for, a heavy concentration of jobs at few locations results in lower job accessibility levels (as firms have to compete harder for workers) than when jobs are less heavily concentrated at more locations. Secondly, compared to the potential measure, the utility-based balancing factor shows, on average, a stronger accessibility growth for the Randstad area in both scenarios for public transport users and, to smaller extent, for car users. Especially for public transport users, the increase in job opportunities within reach as the result of job concentrations around railway stations, is more important than increased labour force competition due to a higher relative job surplus. However, labour force competition significantly affects the spatial distribution of job accessibility. Comparing Figures 4 and 5, we see that the utility-based measure clearly shows relatively lower public transport job accessibility benefits in central urban areas (with relative job surpluses) and relatively higher job accessibility levels in towns and suburban regions in the Randstad area, with a relative shortage of jobs in the reference scenario (e.g. Rotterdam Alexander, Gouda, Almere) and in regions where job competition is reduced due to better access to jobs.

For car users, especially in ILUS-2, the increase in job opportunities and reduced job competition, especially at suburban locations with a relative job shortage, is more important than the reduction of accessibility due to congestion. 2 shows the estimation of the change in Marshallian consumer surplus of the ILUS-1 and ILUS- 2 relative to the reference scenario, using the conventional rule-of-half measure (Equation 7) and the utility-based accessibility benefit consumer surplus measure (Equation 9).

Table 2 shows the total change in consumer surplus in ILUS-1 and ILUS-2 compared to the reference scenario for the year 2030, assuming 220 working days in a year and 1996 price levels. The table shows, firstly, that in agreement with a priori expectations the rule-of-half measure estimates a zero change in consumer surplus for public transport users, since the public transport travel costs do not change. For car users, negative welfare effects are found because of the increase in congestion due to concentration of employment in already congested areas. The accessibility benefit measure, however, shows positive changes in consumer surplus for public transport users, i.e. 5.6 to 5.7 million Euro for the year 2030 in ILUS-1 and ILUS-2, respectively. Interestingly, the change in consumer surplus for public transport users is roughly the same for both scenarios. In ILUS-2, the somewhat lower increase in public transport trips (a 4% increase relative to the reference scenario compared to 6% in ILUS-1) is compensated by higher benefits per trip, which was also illustrated by the balancing factor a_i.

As already described in Section 2.3, Table 2 shows, secondly, that the rule-of-half measure for consumer surplus can easily under- or overestimate accessibility benefits when land-use changes occur. In ILUS-1, the disbenefits to car users are underestimated. In other words, the rule-of-half measure does not account for the reduction of job accessibility for inhabitants of suburban and peripheral areas (as a result of the heavy concentration of jobs in a few central urban areas) when average travel costs between origin-destination locations are not affected. In ILUS-2 the opposite occurs where the rule-of-half measure shows a disbenefit to car users whereas the accessibility benefit measure shows significant benefits. Clearly, when land-use changes occur, not all accessibility benefits are attributable to changes in generalised travel costs, because changes in the relative attractiveness of locations and related changes in trip distribution need to be accounted for. Finally, the accessibility benefit measure shows that scenario ILUS-2, with a less extreme concentration of activities at more locations well-served by public transport should be preferred over ILUS-1 with very extreme concentrations of activities at locations with the highest rail service levels (high-speed rail). A heavy concentration of activities results in disbenefits to car users when road infrastructure remains unchanged, and additional increases in activities show decreasing marginal returns for public transport users.

4. Conclusions

Here, a comprehensive methodology for analysing accessibility impacts and accessibility benefits of integrated land-use/transport strategies, based on location-based and utility-based accessibility measures within a land-use/transport interaction framework has been described and applied in a case study. The case study examined the accessibility impacts and related user benefits of intensive and multiple land-use strategies for the Randstad area in the Netherlands for the 1996-2030 period. The main conclusions drawn are presented below:

Firstly, conventional accessibility measures, which do not account for competition effects between employers on the labour market, such as those for standard potential accessibility, will not accurately measure job accessibility changes. We computed a utility-based balancing factor measure to incorporate the interdependent relationship between the competition on supplied jobs by the population and the demand for workers by firms. Incorporating this competition on the labour market was found to significantly affect the results; i.e. for jobs more concentrated at locations well-accessible by public transport, the utility-based balancing factor compared to the potential measure showed relatively lower job accessibility benefits for public transport users in central urban areas (with relative job surpluses) and higher job accessibility levels in towns and suburban regions in the Randstad area (with a relative shortage of jobs).

Secondly, conventional approaches to measuring accessibility benefits are not capable of fully measuring the total accessibility benefits of integrated land-use/transport strategies, in particular, multiple land-use planning, where simultaneous land-use and transport changes are part of the policy strategy. Literature studies showed that the classical bid-rent location model does not fully capture total accessibility benefits of transport changes. Several authors also indicated that the rule-of-half measure– commonly used in transport project appraisal – estimates accessibility benefits attributable to changes in (generalised) travel costs. However, this does not account for changes in the relative attractiveness of locations due to land-use changes and related changes in trip distribution that take place for reasons other than transport cost changes. Using the rule-of-half measure, a concentration of activities at railway stations would, for example, result in an unrealistic zero consumer surplus change when public transport service levels remain unchanged. In theory, it might be possible to separately deduct the accessibility benefits arising from land-use changes in the land-use system from an appropriate location model (and add these to the rule-of-half estimates). However, we used a more appealing approach, which makes it possible to measure all the accessibility benefits within the transport system, based on utility-based accessibility benefit measures of consumer surplus within an integrated land-use/transport modelling framework. In this way, it can be shown that a concentration of activities well-served by public transport significantly increases accessibility benefits for public transport users. Furthermore, we conclude that a less extreme concentration of jobs around several railway stations is preferred over very extreme concentrations of activities at a few railway stations with the highest service levels (high-speed rail). A heavy concentration of activities results in strong disbenefits to car users without additional road infrastructure investments, and additional concentration of activities shows decreasing marginal returns for public transport users.

Thirdly, and finally, the theoretical soundness of accessibility appraisal not only depends on how accessibility measures are operationalised and measured but also on the theoretical basis and practical limitations of the transport, and land-use data and models used. Ideally, all feedback mechanisms between land use, travel demand and accessibility need to be included. The inclusion of these interdependencies is particularly relevant when analysing intensive and multiple land-use strategies. This may strongly influence location decisions of households and firms in the direct neighbourhood and, on the higher regional scale, result in a redistribution of activities. We showed that the current practice of accessibility appraisal can be improved by using a high-resolution land-use/transport interaction modelling framework, taking into account the relative attractiveness of locations, the regional demand for economic activities, and possible market responses.

Table 1. Average accessibility (working days) for the total Randstad area in the reference scenarios, ILUS-1 and ILUS-2, for 2030

Accessibility measure	Reference scenario 2030		ILUS-1		ILUS-2	
(average for the Randstad area)	Car	Public Transport	Car	Public transport	Car	public transport
			(index reference 2030=100)			
Potential accessibility measure	*1,728,90 0*	*168,400*	*99*	*105*	*100*	*103*
Utility-based balancing factor a_i	*20*	*4*	*100*	*112*	*104*	*127*

Table 2. Change in consumer surplus (million Euro per year) accruing from job accessibility changes for inhabitants of the Randstad area for 2030, ILUS-1 and ILUS-2

	ILUS-1			ILUS-2		
	Car	Public transport	Total	Car	Public transport	Total
	(million Euro)					
ΔCS, rule-of-half	-4.4	0.0	-4.4	-0.7	0.0	-0.7
ΔCS, accessibility benefit measure	-28.8	5.6	-23.4	2.8	5.7	8.5

5. Directions for further research

Further research on the accessibility evaluation of integrated land-use/transport policy strategies, and, in particular, intensive and multiple land-use strategies, could be directed as given below:

Firstly, our analysis here was based on a land-use/transport interaction model which estimates travel behaviour and accessibility measures at a macro level; the model does not include a segmentation of the population. Hence, differences between socio-economic population groups that are known to influence travel behaviour and accessibility levels are not accounted for. However, in earlier work (Geurs and Ritsema van Eck, 2003) it was already concluded that incorporating the match between job and educational level resulted in more accurate accessibility computations. Further research needs then to be directed to computing land use, travel behaviour and accessibility impacts and benefits for relevant socio-economic groups.

Secondly, we focused on job accessibility and home-to-work trips. However, multiple land-use patterns increase the diversity of activities in a given area, which may result in more complex accessibility and travel behaviour patterns as individuals are better capable of combining trip purposes and making multipurpose trips. Traditional trip-based transport models, as applied here, are typically not capable of handling multipurpose trips. This makes a case for analysing all trip motives in a space-time travel behaviour and accessibility framework (see Kwan, 1998; Recker et al., 2001); incorporation of spatial and temporal constraints in accessibility analysis, however, is far from standard practice.

Thirdly, in this paper we examined the user benefits of integrated land-use/transport projects in a case study where quite extreme land-use changes were envisioned. However, the impacts of radical land-use changes might very well be outside the scope of these, or any, land-use/transport model based on observed behavioural responses (e.g. travel demand, cost sensitivity parameters). If future land-use patterns strongly affect travel behaviour patterns, observed behavioural responses may not be accurate, for example, when comparing extreme high density urbanisation patterns or extreme low density urbanisation patterns with the current Dutch urbanisation patterns. More research will be necessary, using stated preference surveys or combined revealed and stated preference surveys, to examine possible behavioural responses of households and firms to radically different land-use patterns, which may then be used as input for accessibility benefit appraisal. To our knowledge, this type of research has, to date, not yet been conducted in the literature.

Fourthly, the option value of accessibility might be relevant for the accessibility evaluation of multiple land-use projects, additional to the benefits accruing to actual users. This value expresses the possibility of people to gain access to goods or services in the future, regardless of the actual use of the good or service (Geurs & Ritsema van Eck, 2001). In this context, people may value the existence of intensive and multiple land-use areas because this offers a high potential accessibility level to many different activities. To date, option values of transport services have been recognised in appraisal guidelines of transport infrastructure projects (e.g., DfT, 2000), but not in land-use policy appraisal.

Fifthly, more research is necessary to evaluate multiple land-use projects using a broad appraisal framework, which includes other economic benefits (i.e. the wider economic benefits) and costs, and non-economic benefits and costs. To aggregate the different items, a combination of cost-benefit and multi-criteria analysis will be necessary. This is because, for many of the benefits, it will be difficult to derive a monetary value, for example, the perception and appreciation of the visual quality, aesthetics, and quality of life and social safety aspects of multiple land-use areas.

Finally, a thorough appraisal of intensive and multiple land-use projects requires a high spatial resolution of land-use modelling. In this paper we used a spatial resolution of 500-metre grid cells, which is sufficient to model land-use and transport impacts on the local and regional level but too coarse to model impacts at the project level. The development of land-use and transport models with higher spatial resolutions will be necessary for a more detailed analysis of transport and accessibility impacts, and also to evaluate social and environmental impacts of multiple land-use projects such as severance, noise and local air quality.

Footnotes

[1] A new Dutch national spatial planning policy document was published in April 2004, and a new national transport policy plan is planned for publication in late 2004. Policy proposals in these documents are not included in the analysis because at the time of writing the decision-making process had not been finalised.

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